IMPACT OF SOY-BASED BIODIESEL BLENDS ON OFF-ROAD ENGINE EMISSIONS: THE CASE OF TRANSPORTATION REFRIGERATION UNITS

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California Environmental Protection Agency

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Introduction

- This project is part of a multimedia evaluation on the use of biodiesel as an alternative to diesel fuels.
- The data will be used to support two of the Air Resources Board's major programs: a) the Diesel Risk Reduction Program and b) the Low Carbon Fuel Standard.
- Previous studies had found that biodiesel reduces gaseous emissions and particulate matter (PM). However, these studies also had reported a slight increase of Nitrogen Oxides (NO_x) emissions.
- This presentation includes quantitative emission data for: THC, CO, CO_2, CH_4, NO_x, N_2O and PM for soy-based biodiesel blends B5, B20, B50 and B100 compared to California ultralow sulfur diesel (ULSD/B0).

Fuel Properties

	ULSD	Biodiesel B100
Cetane #	57	48
Sulfur, ppm	3.3	0.7
C Residue, wt%	0.03	0.033
Aromatics, vol%	18.6	NA
Nitrogen, ppm	0.8	NA
Glycerin	N/A	0.08
Water	<0.02	<0.01
T90, °F	615	662
Flash Point, °F	153	337
Viscosity@40°C	2.9	4.2

Fuel source: Stepan®Biodiesel SB-W

Experimental Method

- Test cycle follows ISO 8178, Part 4 “Test Cycle Type C1 ‘Off-road Vehicles, Industrial and Medium/High Load.’”
- Emission measurements follow CFR Title 40, Part 89 and partially 1065 (monitoring flow and temperature at the sampling filter, and filter weighing accordingly).
- The TRU engine (Pre Tier 1 - 1998 Kubota) was operated in 8 steady-state modes on a small engine dynamometer.
- The duration of each mode was 5 min (300 sec).
- The average concentrations (ppm) of CH_4, CO, CO_2, and NO_X, in each mode were measured from Tedlar bags using Horiba CVS system and AVL AMA 4000 analyzer bench.
- The average THC concentration (ppmC) in each mode was measured using a Horiba CVS system and an AVL Heated FID analyzer.
- N_2O was measured by GC-Electron Capture Detector (ECD) method for each mode.
- All average emission concentrations (ppm) were converted to average emission rates (g/h).
- PM was collected and weighed separately for each mode, and converted to the average emission rate (g/h).
- Weighted specific emissions (g/kWh) were calculated based on weighted factor and engine power of each mode

8-mode Test Parameters

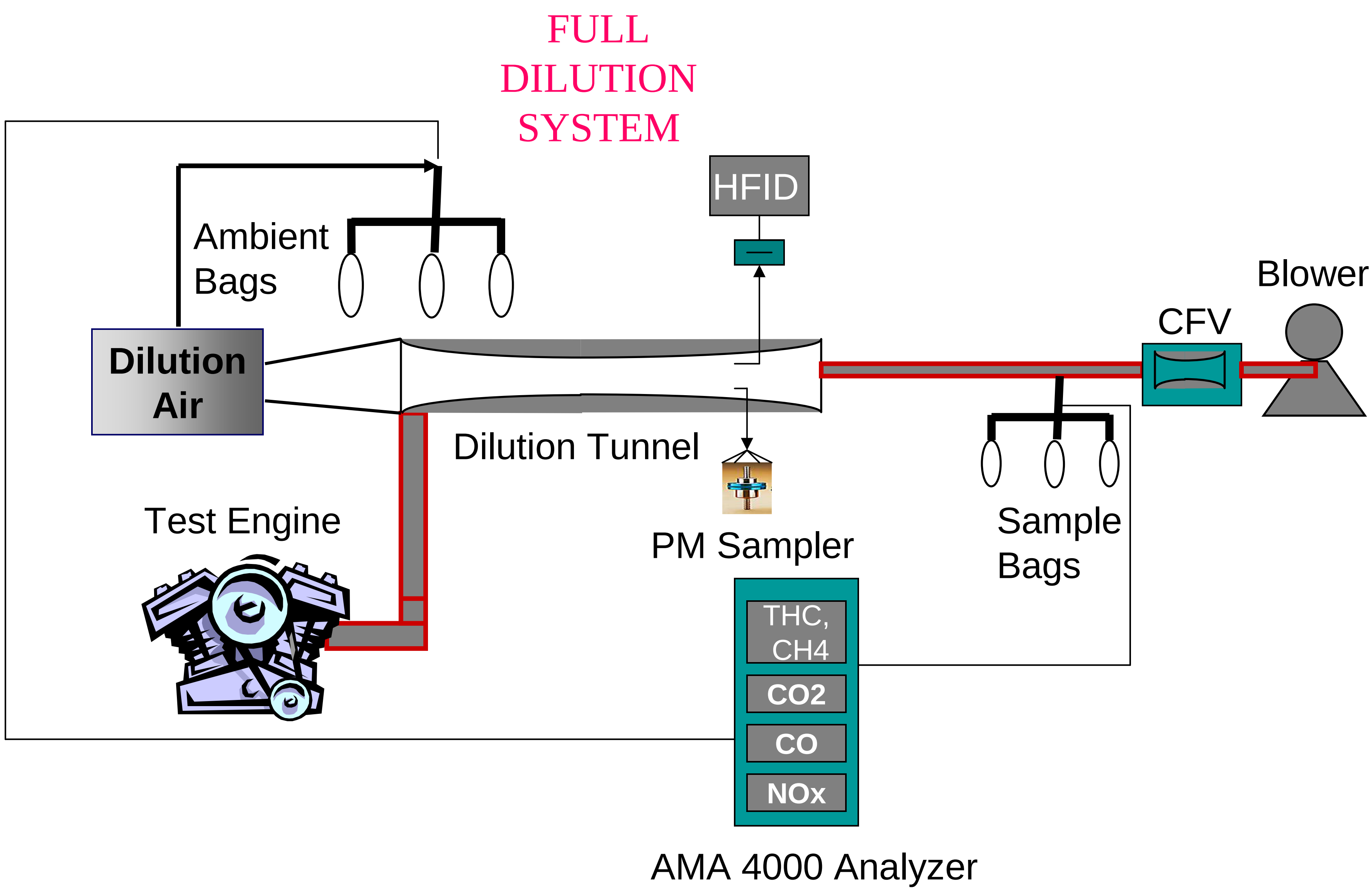
Mode	Speed	Torque %	Weight Factor
1	Rated*	100	0.15
2	Rated	75	0.15
3	Rated	50	0.15
4	Rated	10	0.1
5	Intermediate**	100	0.1
6	Intermediate	75	0.1
7	Intermediate	50	0.1
8	Idle	0	0.15

Rated speed ~ 1900 rpm

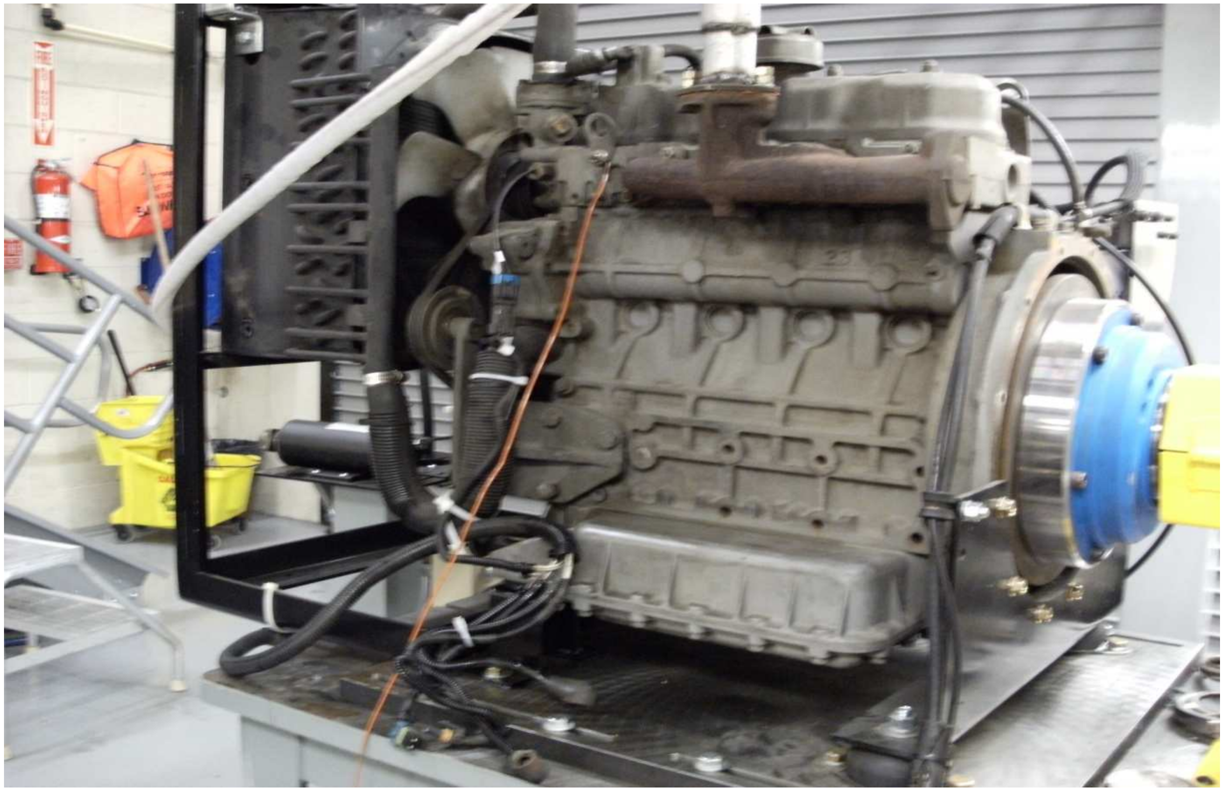
Intermediate speed ~ 1430 rpm

Idle ~ 1035 rpm

Schematic of Engine Testing



Test Engine Specification



Manufacturer: Kubota

Year & Model: 1998 V2203-DIB

Displacement: 2197 cc

Power Rating: 37.8 HP (actual power ~ 27.6 HP)

Speed Rating: 2200 RPM (actual rated speed ~ 1900 RPM)

Engine Type: In-line 4 cylinders, 4 stroke (Pre-Tier 1)

Data Collection and Analysis

The average weighted emissions (g/kWh) of each pollutant was calculated based on eight 8-mode tests per fuel. Series 1 was run from October 2009 to mid January 2010 and Series 2 from late January to July 2010. Each replicate was run sequentially in order of baseline and increasing percent biodiesel.

Series 1: ULSD=B0, B50, and B100
Series 2: ULSD=B0, B5, B20, and B100

A t-test was performed between each specific blend and their series baseline (ULSD=B0). In addition the two series were standardized to the specific baseline to assess overall trends using regression.

Series 1: ULSD=B0, B50, and B100

	Bio Percent	THC(HFID) g/kW-hr	CH_4 g/kW-hr	CO g/kW-hr	CO_2 g/kW-hr	NO_X g/kW-hr	PM g/kW-hr	N_2O* g/kW-hr
Avg	0	1.87	0.084	7.47	821.1	12.24	1.94	0.0153
Avg	50	1.44	0.052	5.79	832.5	13.44	1.62	0.0143
Avg	100	0.80	0.026	3.81	845.4	14.83	1.22	0.0134
SD	0	0.10	0.011	0.42	3.0	0.38	0.08	0.0008
SD	50	0.13	0.008	0.33	3.0	0.52	0.11	0.0005
SD	100	0.18	0.004	0.28	3.6	0.63	0.16	0.0005
n	0	7	7	7	7	7	7	7
n	50	9	9	9	9	9	9	9
n	100	8	8	8	8	8	8	8
% Diff	50-0	**-23**	**-38**	**-22**	**1**	**10**	**-17**	**-6**
% Diff	100-0	**-57**	**-69**	**-49**	**3**	**21**	**-37**	**-13**

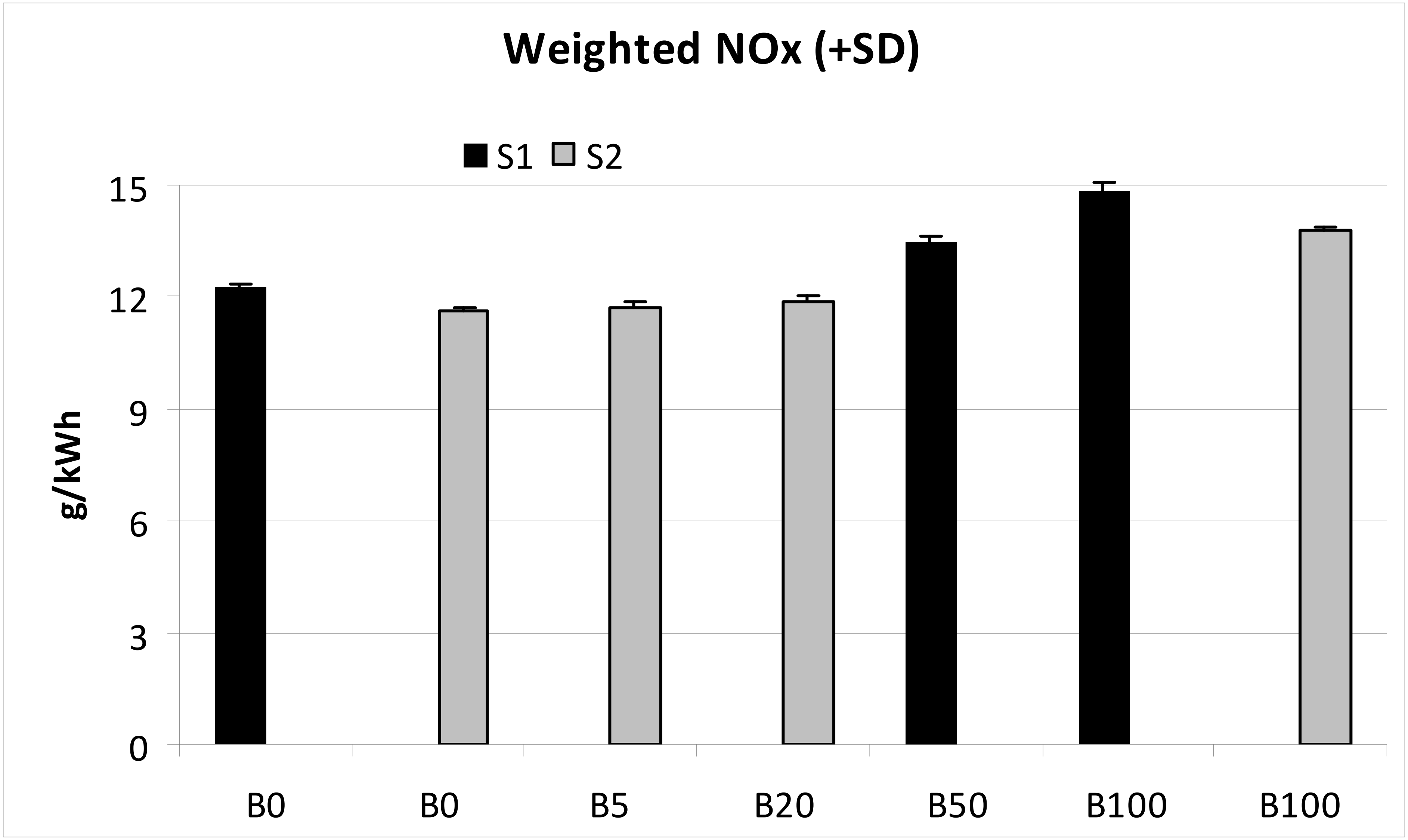
Bold: Statistically significant *Italic: Statistically non-significant*

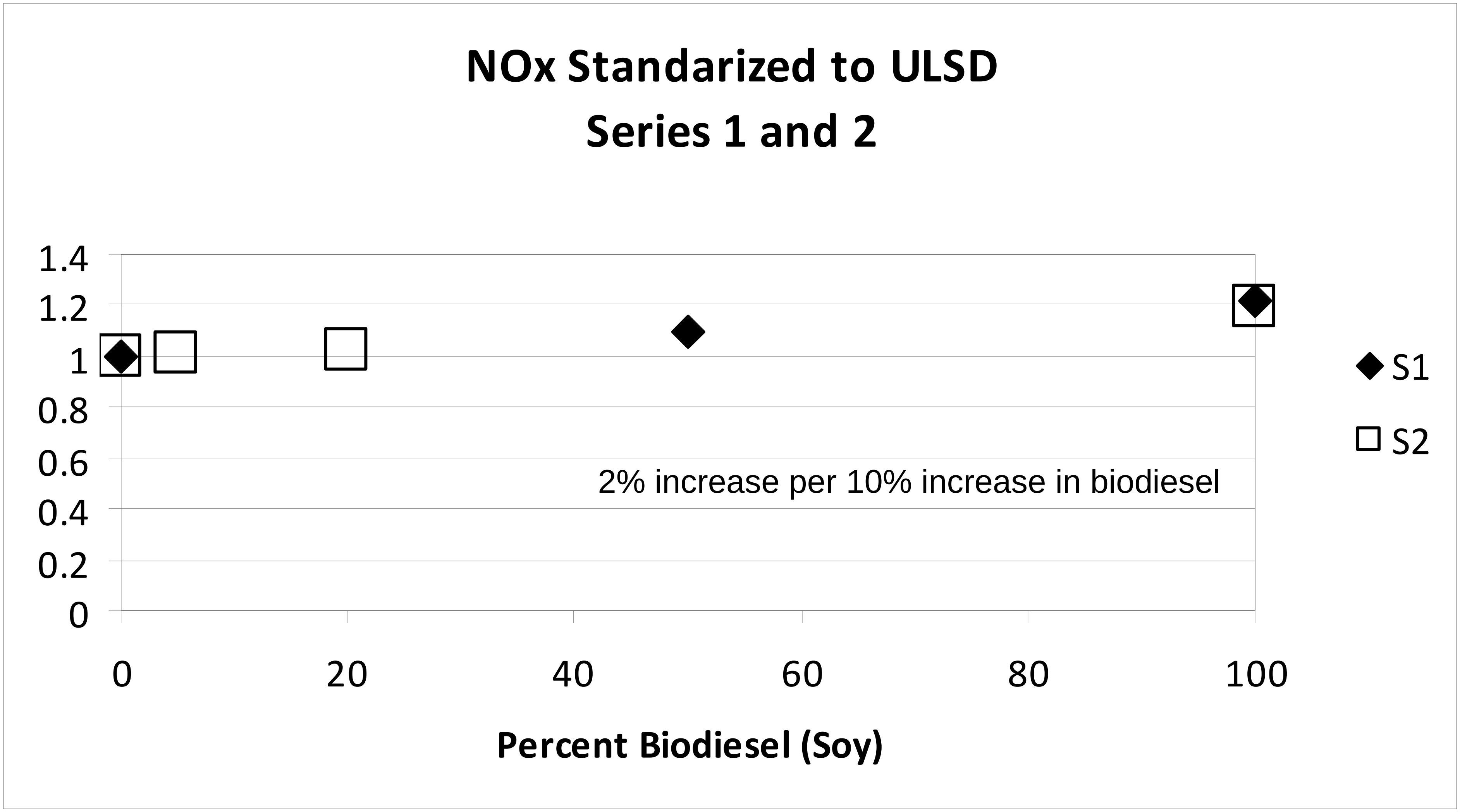
*N2O was only tested in this series

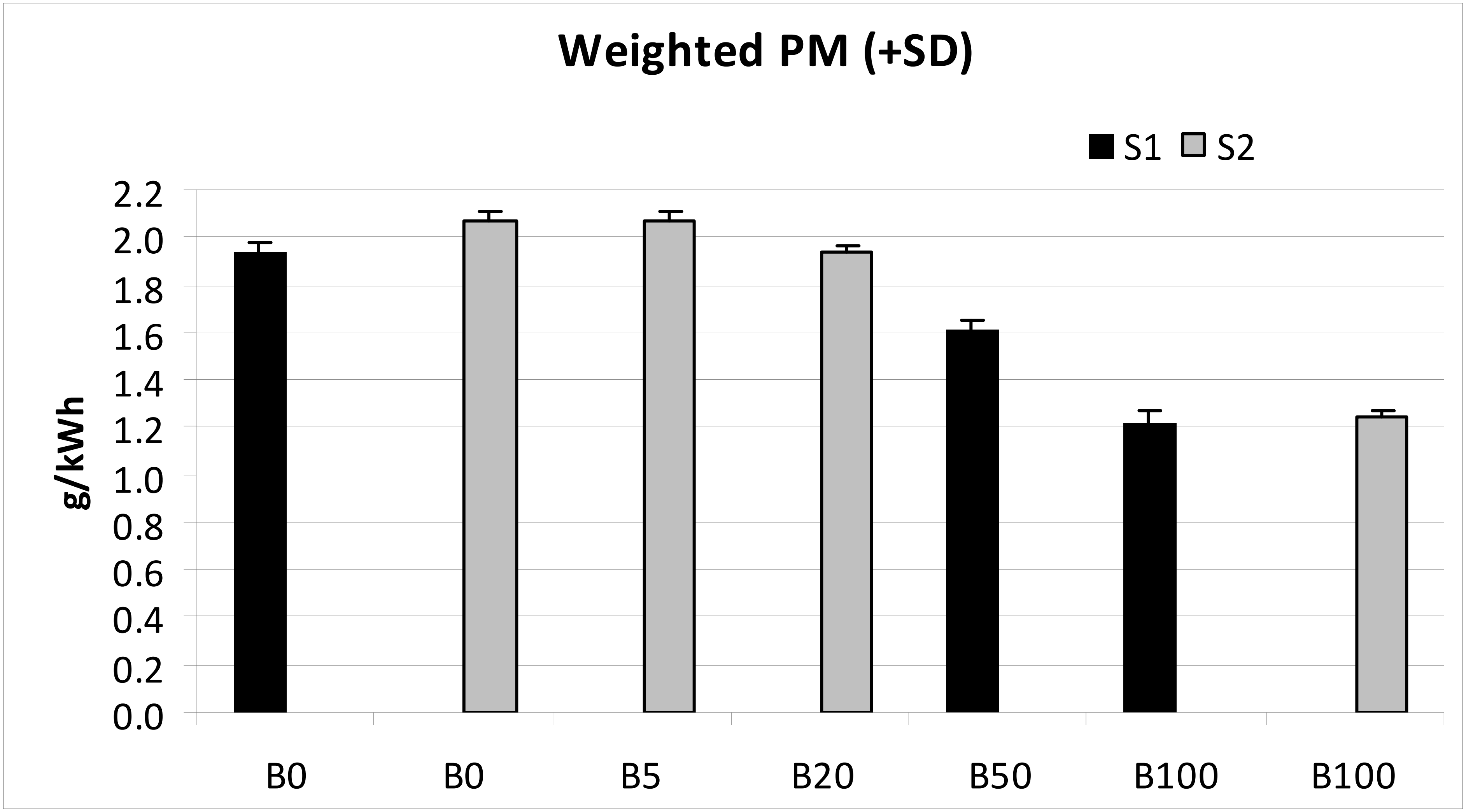
Series 2: ULSD=B0, B5, B20, and B100

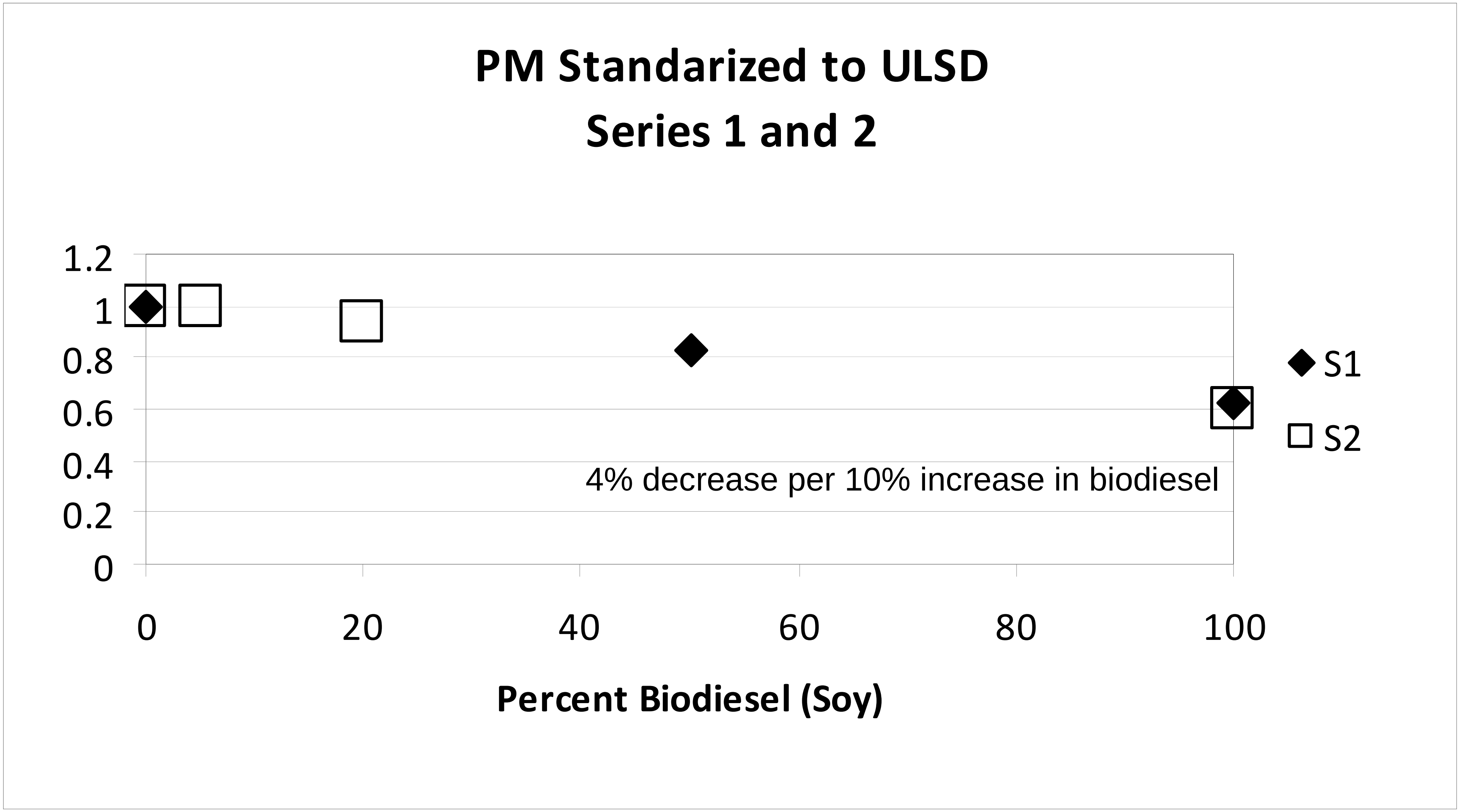
	Bio Percent	THC(HFID) g/kW-hr	CH_4 g/kW-hr	CO g/kW-hr	CO_2 g/kW-hr	NO_X g/kW-hr	PM g/kW-hr
Avg	0	1.72	0.110	8.30	837.6	11.62	2.08
Avg	5	1.77	0.105	8.18	836.9	11.74	2.07
Avg	20	1.62	0.095	7.63	841.4	11.89	1.93
Avg	100	0.71	0.032	4.13	854.9	13.82	1.24
SD	0	0.14	0.014	0.51	5.1	0.30	0.13
SD	5	0.13	0.012	0.33	5.7	0.27	0.10
SD	20	0.15	0.009	0.38	5.1	0.34	0.09
SD	100	0.08	0.003	0.22	2.7	0.19	0.07
n	0	11	11	11	11	11	11
n	5	8	8	8	8	8	8
n	20	9	9	9	9	9	9
n	100	5	5	5	5	5	5
% Diff	5-0	*3*	*-4*	*-1*	*-0.1*	*1*	*-0.1*
% Diff	20-0	*-6*	**-14**	**-8**	*0.5*	*2*	**-7**
% Diff	100-0	**-59**	**-70**	**-50**	**2**	**19**	**-40**

Bold: Statistically significant *Italic: Statistically non-significant*

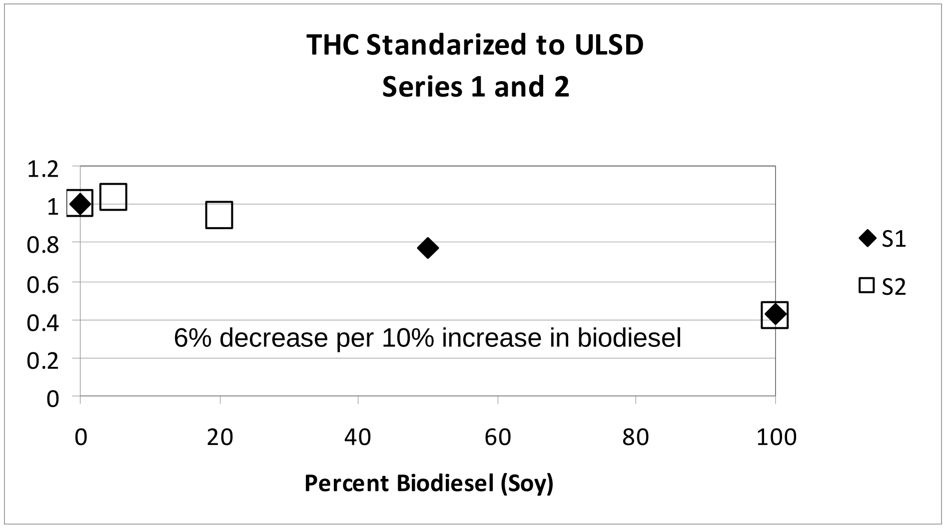

Weighted NOx (+SD)
S1
S2
15
12
9
6
3
0
g/kWh
B0
B0
B5
B20
B50
B100
B100

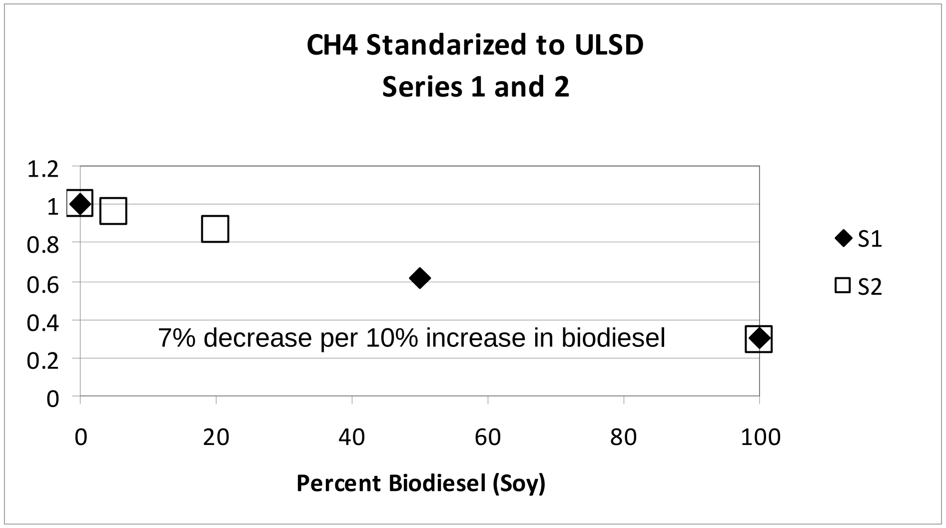

NOx Standarized to ULSD
Series 1 and 2
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Percent Biodiesel (Soy)
S1
S2
2% increase per 10% increase in biodiesel

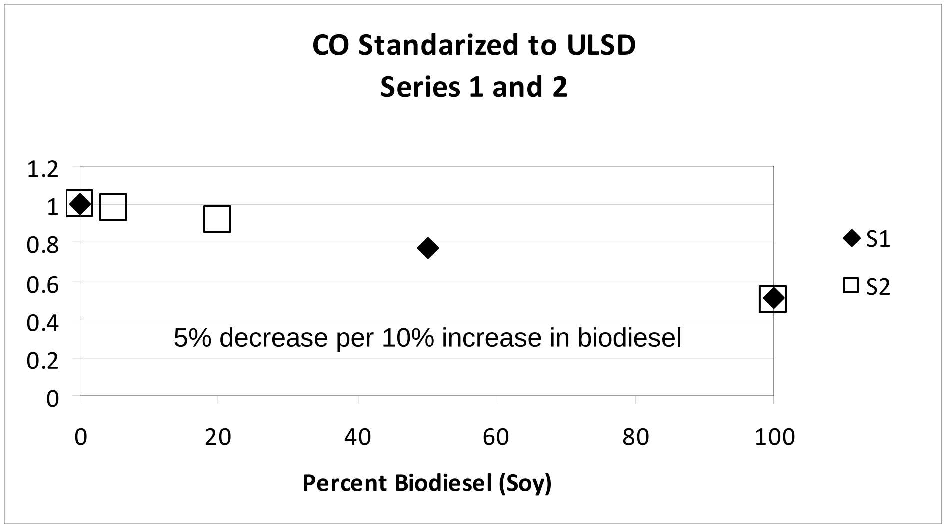

Weighted PM (+SD)
S1
S2
g/kWh
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
B0
B0
B5
B20
B50
B100
B100

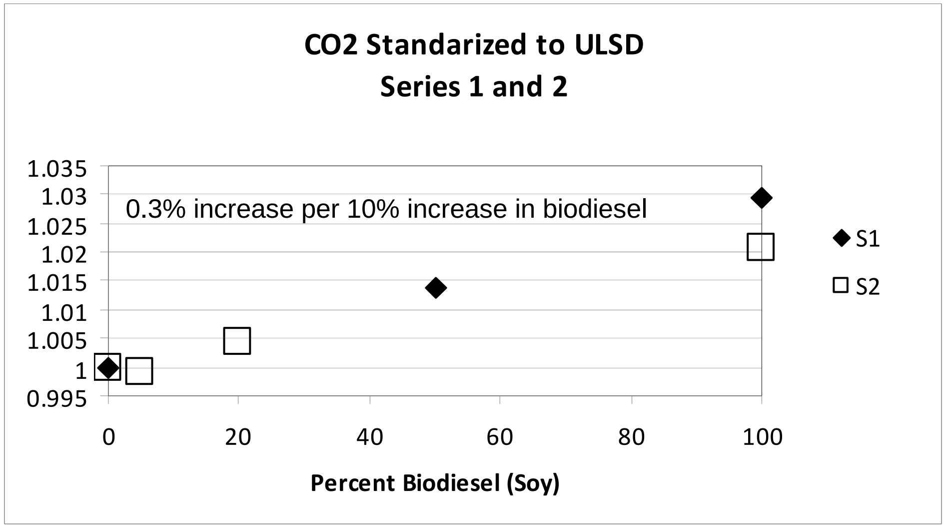

PM Standarized to ULSD
Series 1 and 2
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Percent Biodiesel (Soy)
S1
S2
4% decrease per 10% increase in biodiesel

Changes in emissions due to the use of biodiesel (soy) for THC, CH_4, CO and CO_2

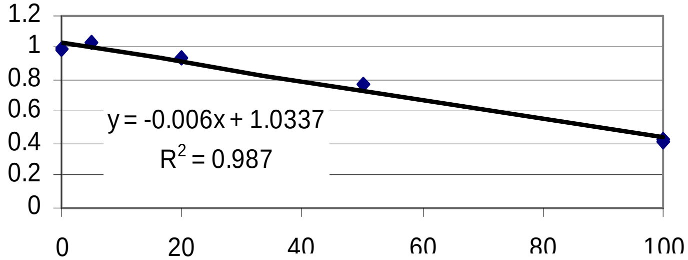




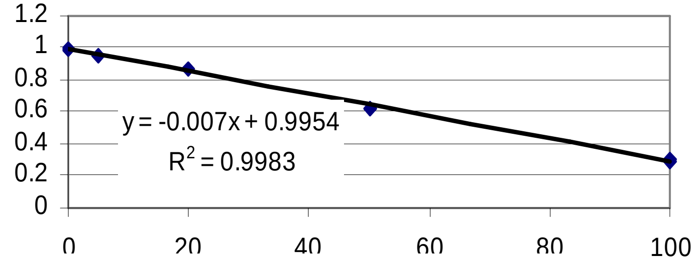




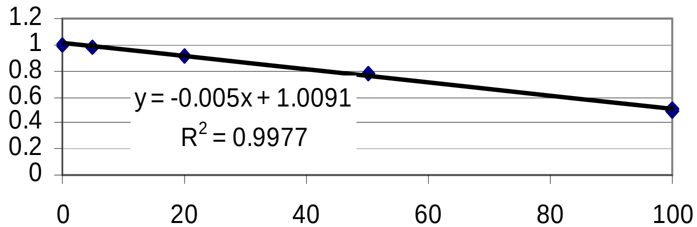
Summary of standardized trends



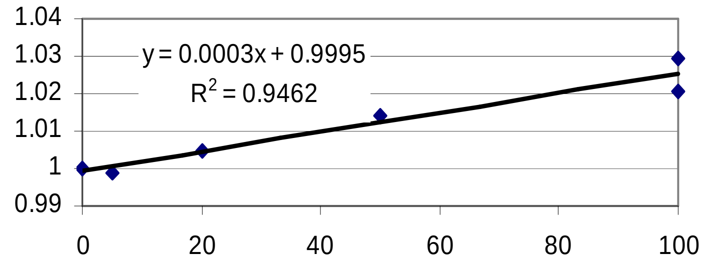
THC



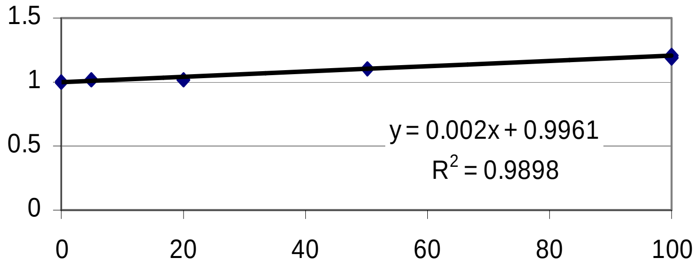
CH4



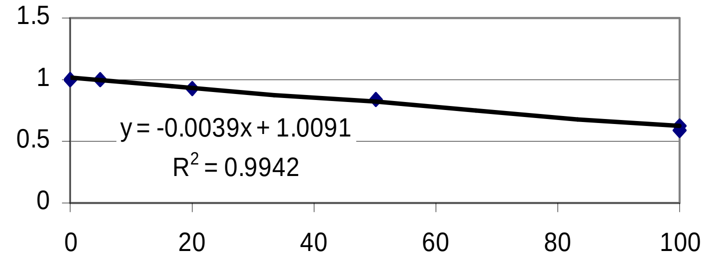
CO



CO2



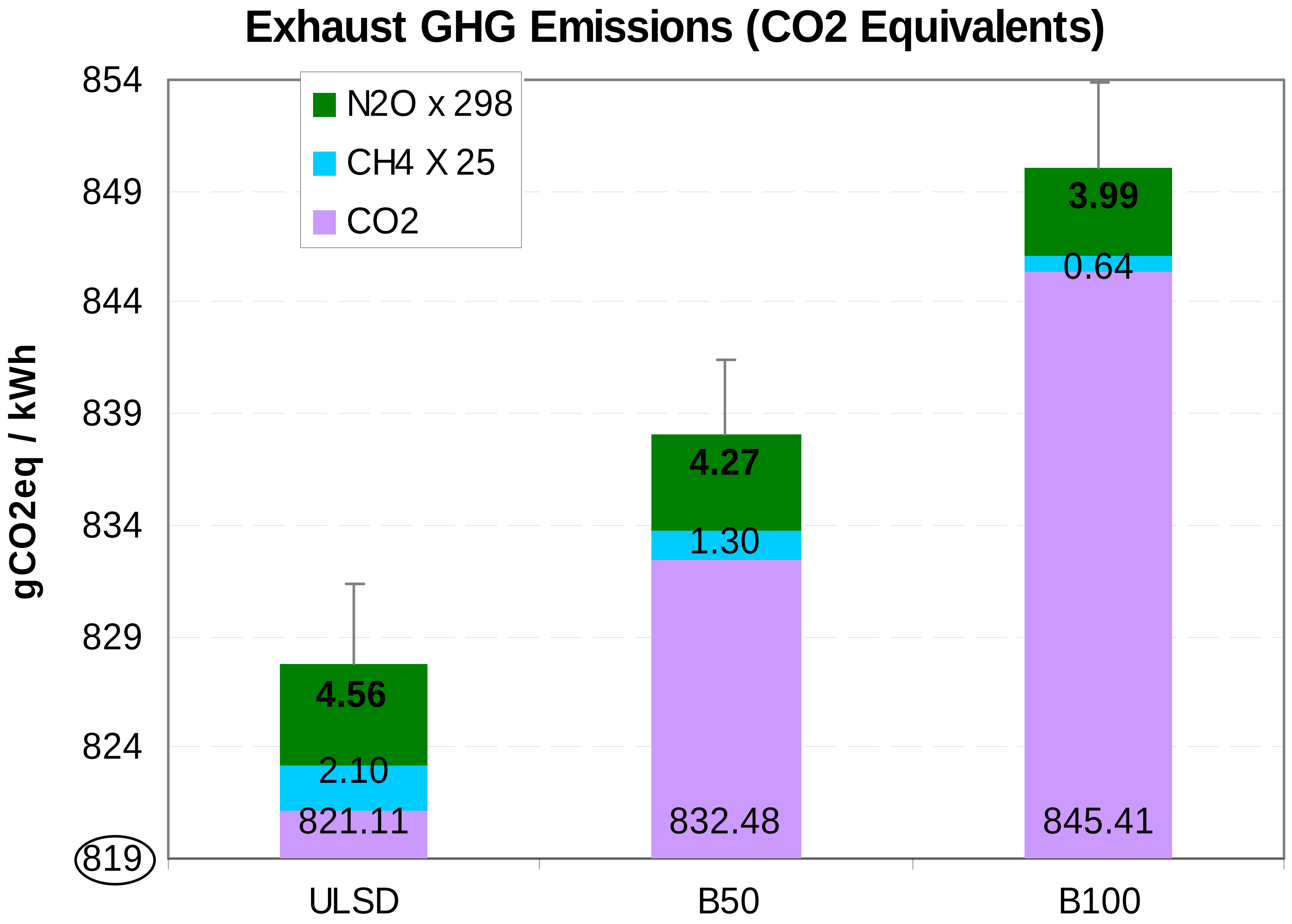
NOx



PM

Percent Biodiesel

Percent Biodiesel

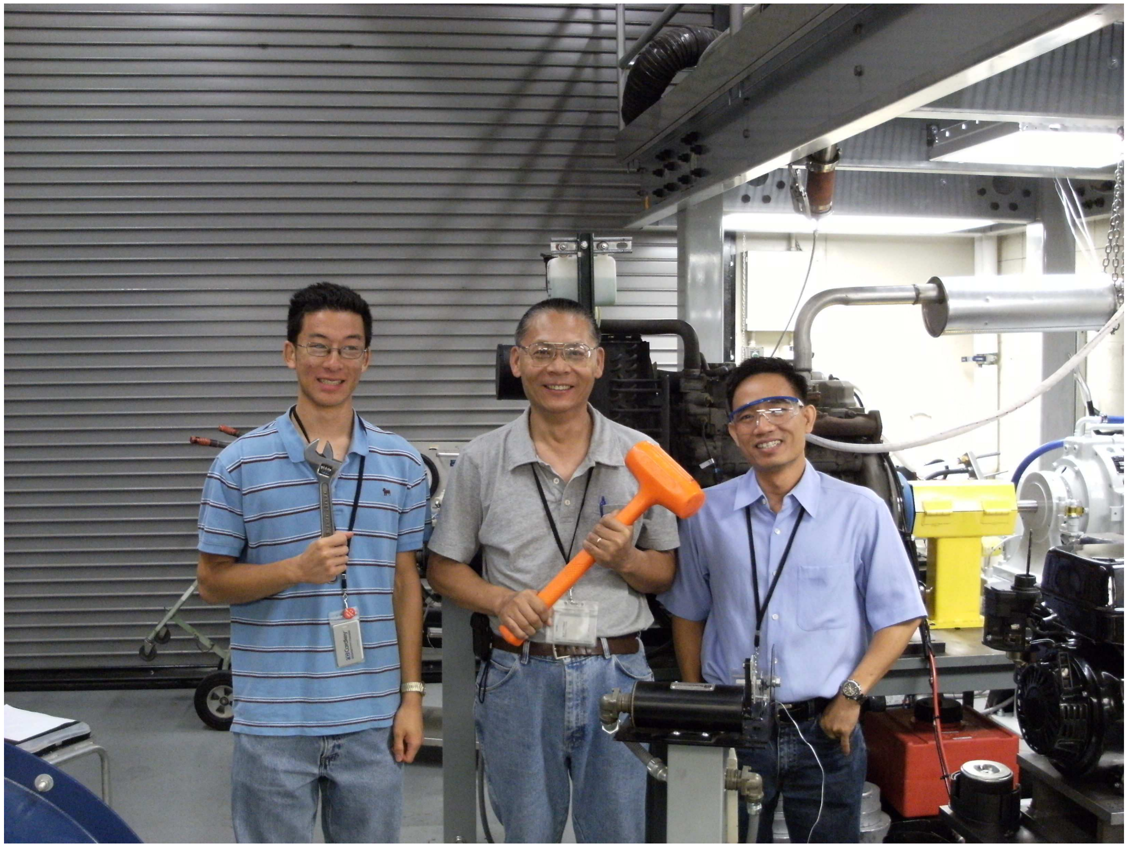


Exhaust GHG Emissions (CO2 Equivalents)
gCO2eq / kWh
854
849
844
839
834
829
824
819
N2O x 298
CH4 X 25
CO2
4.56
2.10
821.11
4.27
1.30
832.48
3.99
0.64
845.41
ULSD
B50
B100

Conclusions

- Emission reductions were observed with the use of biodiesel for THC, CH_4, CO and PM which increased with the percent usage of biodiesel.
- Slight emission increases for NO_x and CO_2 were observed which increased with the percent usage of biodiesel.
- For this sample size, statistically non-significant changes were observed between ULSD emissions and B5 for all parameters and for THC, NO_x, and CO_2 for B20.
- Emission reductions were observed between ULSD and B50 and B100 for N_2O.
- Both N_2O and CH_4 accounted for less than 1% of the total CO_2 equivalent greenhouse gas emissions.

Acknowledgements



The TRU team wants to thank all the other ARB employees that supported this project